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# WATER DEMAND MANAGEMENT: A REVIEW ON THE MECHANISMS TO REDUCE WATER DEMAND AND CONSUMPTION

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## ABSTRACT

*Securing water supplies in urban areas is a major challenge for policy makers, both now and into the future. In mitigating threats of a water shortage, a number of initiatives and programs have been implemented, which includes water demand management (WDM). A number of studies have analyzed the usage of various mechanisms to manage water demand. In this paper, we review the implementation and the effectiveness of the mechanisms of price, technology, communication /education and restriction in reducing domestic water demand. Based on the review, we have found that the effectiveness of the mechanisms varies from one mechanism to another, where rainwater harvesting system was found to yield the greatest water demand reduction, while communication/education yields the lowest. Despite the different approach, most of the cities reviewed used integrated implementation of the mechanisms to reduce water demand, which shows that the mechanisms need to be combined in order to maximise water demand reduction. However, currently there are still very limited studies conducted on the effective implementation of integrated mechanisms. Thus, more work is needed in order to strategize the usage of these mechanisms in maximising water demand reduction. It is expected that this study can assist water authorities in designing and conducting an effective WDM program in order to maximise water demand reduction.*

**Key words:** Water Demand Management; Price; Technology; Restriction; Communication; Education; Mechanisms; Sustainability; Sustainable City.

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# 1. INTRODUCTION

There have been long arguments in literatures on the issue of shortage and depletion of resources, including freshwater resources [1]. The global communities have to consider that presently, freshwater resources are indeed being strained, and thus may create risks on the development and sustainability of cities [2]. Currently, there are a number of regions that are undergoing regular water stress which includes South Africa, Australia, the Central U.S. and India [3] and by 2020, 35 countries will likely be water scarced [4]. It is estimated that by 2025, a third of the developing world`s population will likely to have severe water shortages [5]. The mining of groundwater too is currently unsustainable, as was the case in major grain producing areas such as China, India and the U.S. [6].A water shortage can affect the sustainability of a city and, along with food and energy, is regarded as one of the global risk to be monitored and mitigated [6]. These figures underline the importance of water management to sustain the development of cities.

A number of initiatives have been implemented around the world to mitigate threats of a water shortage. These initiatives can generally be categorized into a) increasing supply and b) managing demand [7]. From the 'increasing supply' approach, water is considered as a `requirement` of a society that has to be met, instead of a `demand` that is more flexible. Thus, this approach emphasizes expanding facilities to meet expected increasing water demands. However, focusing solely on water supply facilities without due thought to demand determinants and management is not sustainable, due to the impact on the environment as well as potential limitations to local water supplies [8]. Water management is moving away from increasing supply sources and is focusing on water demand management (WDM). In general, WDM can be defined as the development and implementation of strategies to influence and reduce water demand to manage water allocations within sustainable supply options [9]. Through WDM, solutions such as development of a new water supply facility are only recommended once strategies for reducing the water demand have been fully analyzed and implemented.

There are two types of mechanisms commonly used by water authorities in reducing and managing water demand, which are price [10] and non-price [11]. Studies on WDM have shown that different mechanisms reduce water demand differently. For example, Mayer[12] found that water saving technologies can reduce water demand from 0.1% through the installation of dishwashers, up to 13% through the usage of low-flow toilets. This means that the water demand reduction for households owning low-flow toilets should be greater than households owning dishwashers. In another example, the UK Environment Agency [13] found that communication and education can reduce water demand to up to 5.6%, while Dandy [14] found that the mechanism of price had the elasticity of ranging from -0.6 to -0.8. Hence, due to the different effectiveness, the usage of these mechanisms by the water authorities needs to be strategized in order to maximise water demand reduction. This paper will review the usage and effectiveness of some of the mechanisms used by water authorities in managing water demand and consumption. The result from this work, in turn, can be used as a base in advancing towards a better and more sustainable management of water resources.

## 2. PRICE MECHANISM

The pricing of water is one of the earliest considered factors in domestic water demand and had emerged as one of the appropriate tools in water demand management [15]. The basic sense of price mechanism is that, as the price escalates, the consumption would decrease. Some of the authors working on domestic water had studied the elasticity of water demand and price, and generally found that demand reduction is comparatively lower than price rise, where the elasticity values of price and water consumption were between 0 and -1 depending on time and usage [16,17]. In term of time, Espey [18] found that the price elasticity value for median long-run was -0.64 and -0.38 for the short run, which means that the price mechanism is more effective in the long run. In another study, Dalhuisen [19] found that the more time households need to adapt to the increment of price, they will be more responsive to price changes.

In term of water demand and usage activities, price elasticity of the demand approaches -1 when it involves water leisure activities (i.e. swimming pools and garden watering). This means that the usage of price mechanism is more effective when dealing with this type of activities. However, the relation of price and water demand was found to be not as accurate when dealing with more basic usage of water (i.e. drinking, personal hygiene) [19,20]. In line with basic water needs and pricing, Martínez-Espiñeira and Nauges [21] discussed the existence of a threshold of water needed for satisfying basic and essential needs. They argued that while the water usage below the threshold will be very much less responsive to pricing, price variation will greatly influence the water usage above the threshold.

There exist significant variations in price elasticity for different income groups and regions. Dalhuisen [19] found that the average price elasticity ranged from -0.005 in both the eastern and western US, to -0.28 in Europe, while Dandy [14] found that the price elasticity ranged from -0.6 to -0.8 in Australia. In term of income, it had been reported that middle income households were more impacted by price rise as compared to the high income households and low income households [22]. This may be due to the increment of price simply could not curb the demand of the high income households due to their strong financial strength, while the low income households were already using water for fulfilling their basic needs, which is within the threshold discussed by Martínez-Espiñeira and Nauges [21]. This may have caused the high and low income households to be less sensitive to price rise, as compared to the middle income households.

Apart from that, water rate structure also plays an important role in water demand (Olmstead et al.,2007). There are 3 rate structures typically used by water utilities: uniform rate (UR), increasing (IBR) and decreasing block rate (DBR). According to Dalhuisen et al. (2003) and Espey et al.(1997), the value of own price elasticity was between -0.34 to -0.62 for an increasing block rate, and -0.14 to -0.38 for a decreasing block rate. In another study by Olmstead [10] in eleven US cities, they found that the own price elasticity for increasing block rate was -0.55 (i.e. 5.5% decrease in water demand for every 10% increase of price), as compared to -0.33 for a uniform rate structure.

## 3. TECHNOLOGIES MECHANISM

### 3.1. Water Efficient Appliances

One of the important strategies in WDM is the installation of water efficient appliances. Water efficient appliances can be considered as an effective mechanism to reduce water demand due to three reasons [23]. Firstly, a significant share of domestic water is consumed through the appliances (e.g. toilets, showers, washing machine). Secondly, from the

perspective of engineering, the water saving potential of these fixtures is well acknowledged (e.g. water efficient washing machine could be using just a third of an inefficient model). And thirdly, the promotion of installation of these appliances is politically better as compared to policies on water price and restrictions. Studies on water saving appliances in the USA, UK and Australia found that the installation of the appliances, including faucet aerators and low-flow showerheads reduced water consumption by 12% [24]. Turner [25] reported that 12% reduction in water consumption was obtained in Australia through the replacement of inefficient fixtures and the checking and repairing of leaks. Furthermore, according to Inman and Jeffrey [7], a more comprehensive program for retrofitting water efficient appliances may reduce water consumption by 35% to 50%.

Among the most comprehensive studies conducted on the effect of retrofitting water efficient appliances in households were the studies conducted by Mayer [12,26,27] in the cities of Seattle, Tampa Bay and East Bay Municipal Utility District (EBMUD). In the studies, a group of sample houses were retrofitted with a range of water saving appliances including water efficient washing machines, dishwashers, faucet aerators, low-flow showerheads and ultra-low flow toilets. Furthermore, water audit for the checking and repairing of leaks were also conducted. The water saving due to the appliances were then obtained based on the comparison of water consumption before-and-after the retrofit. The highest reduction came from the repairing of leaks, with the reduction of 19.7%, while the lowest came from the installation of dishwashers, with the reduction of 0.3% (Figure 1). In term of regions, the highest water reduction was recorded in Tampa Bay with the total reduction of 49.7%, while the lowest was recorded in Seattle with the total reduction of 37.2%. Overall, with the exception of leaks, the installation of water efficient washing machines, dishwashers, faucet aerators, low-flow showerheads and ultra-low flow toilets reduced indoor water consumption by up to 30%.

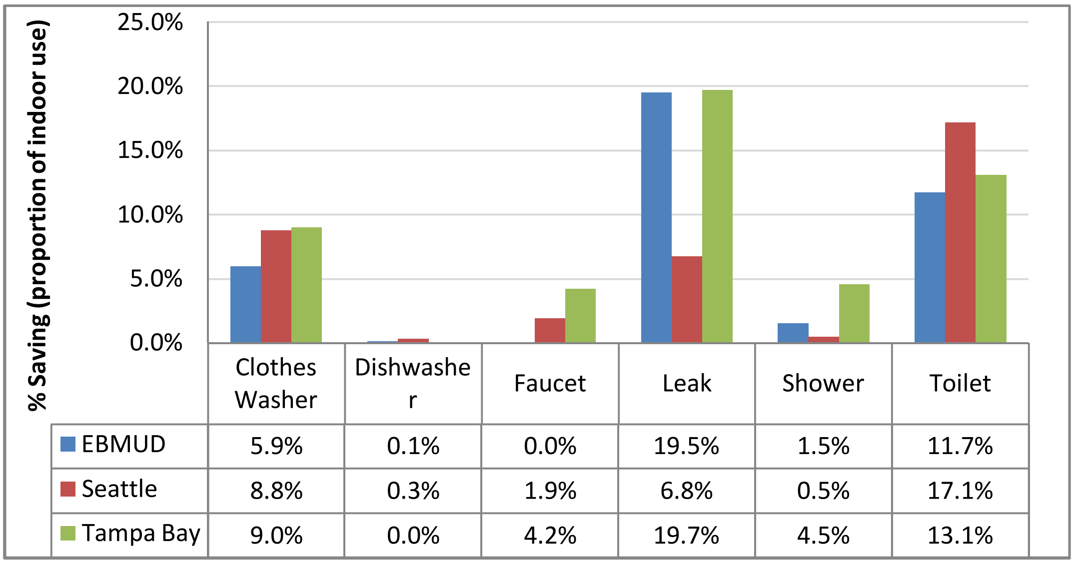


**Figure 1** Percentage savings due to the installation of water saving appliances [12,26,27]

### 3.2. Decentralized Supply System

Apart from water efficient appliances, it is also possible to secure water supply by installing a decentralized water supply to houses. Among the most used decentralized water supply system is the rainwater harvesting system (RWHS) and greywater recycling system (GWRS). There have been a growing number of studies analysing different parameters of the rainwater harvesting system, including on the analysis of the quality of the stored rainwater [28], the

evaluation of the optimum size of rainwater storage tanks [29,30] as well as the estimation of the potential mains water saving due to the installation of rainwater harvesting systems [30,31]. Some of the studies have also analysed the side effects of rainwater harvesting system, including on the changes to runoff characteristics [32] and the environmental advantages [33,34].

Rainwater harvesting can be effectively targeted in substituting mains water supply to non-potable end uses, including for toilet flushing, garden irrigation and washing machines [35]. Based on the results of the investigations on the micro-component of household water end use, a significant part of domestic consumption is typically used for toilet flushing, laundry and outdoor [12,26,27,36,37]. Thus, non-potable water constitutes a significant part of household water consumption, and a potentially high water savings can be obtained by the usage of rainwater harvesting system. There have been a growing number of studies showing the suitability of rainwater harvesting as an alternative source for saving potable water. In southern Brazil, Ghisi [30] found that the potential mains water saving ranged from 12% to 79%. In the UK, Fewkes [38] found that the average mains water saving from the usage of rainwater for toilet flushing alone was approximately 57%. While in Taiwan, Cheng [39] found that the potential of mains water saving can be up to 32%, with rainwater used mostly for toilet flushing, cleaning and gardening.

Apart from RWHS, some studies have also analysed the usage of decentralized greywater recycling system for domestic water supply. Greywater can be defined as wastewater that is produced from sources apart from toilets, which can constitute about 75% of the residential sewage [40].According to Karpiscak [41], 30% of the total household water consumption could be saved through the usage of greywater for toilet flushing alone. Furthermore, it was estimated by Friedler and Galil [42] that 50 MCM/year (million cubic meters per year) of mains water in Israel could be saved by 2023 should the greywater recycling system obtained 30% penetration ratio in the country. The author further demonstrated that it is possible to reach 30% penetration in 20 years' time, provided that the government provides support through encouragement and promotion.

## 4. COMMUNICATION/EDUCATION MECHANISM

For this paper, the mechanisms of public information campaign and education will be combined under communication/education. One of the most vital objectives of communication/education is to engage the public on the issues of water conservation [43]. In a study by Baumann [44], it was reported that communication/education effort, such as through media broadcasts, can reduce water demand by 2% - 5%. According to Billings and Day [45], a function of water consumption and public information on the need to conserve water had an elasticity of -0.05. This means that for every 10% increase in the amount of publicity efforts, there will be an approximately 0.5% reduction of water consumption. However, there were no explanations provided by the authors on how this was measured but they concluded that, despite the expected reduction that can be gained from publicity, the effect is temporary, and will only last as long as the publicity continues.

In a study by the UK Environment Agency [13] on Zaragoza public education campaign, it was found that longer term water saving can be realized through boosting consumers involvement with the community as well as educating the consumers. The Zaragoza public education campaign was conducted in two stages. The first was identifying and bringing the water efficient appliances` suppliers to be in contact with the local community, and the consequent step was notifying the public on the practicalities and benefits of conserving water through school visits, exposition and public presentations. An evaluation carried out

one year after the program found that the program reduced annual water consumption of the city by 5.6%. In another study, Wang [46] analysed the effect of public education program put forward by Artesian Water Company Inc. in the area of New Castle County of Delaware. In the program, the company used pamphlets and bill inserts as the mean to inform consumers on water conservation. The study had found that the program reduced summer water demand by 4.8% between the years 1992 and 1997.

It was also found that communication/education have different effects for different regions, particularly in regions with different dry environment. For example, the study by Nieswiadomy [47] on the effect of communication/education efforts in four regions in the US – southern region, western region, north east region and central region, found that the only region most impacted by the efforts was the western region, which is more prone to water scarcity. Similarly, Renwick and Green [20] found that demand side policies, including public information campaigns reduced water demand in the western region of the US by 8%, while Howarth and Butler [43] found that information campaigns had no effect in Swindon, UK. This phenomenon can be explained by the work of Gersick [48] who argued that radical change generally only occurs if those involved perceived a significant crisis.

## 5. RESTRICTION MECHANISM

Among the approaches used to reduce water demand during times of scarcity is the usage of water restriction. According to Halich and Stephenson [49], there are three basic components in a restriction; program content, program promotion and information dissemination, and enforcement. Program content refers to the type and the extent of water use restrictions, where the greater the number of activities restricted, the higher the reductions in the water consumption that can be expected. Program promotion and information dissemination on the other hand, should convey to the public four general elements; the seriousness of the water situation, the restricted activities, the penalties for non-compliance and the promotion of additional ways to reduce water consumption. Finally, restriction program requires a system of enforcement, which involves monitoring and penalizing offenders. Monitoring can include both passive efforts (e.g. citizen hotlines) and active efforts (e.g. public works department or police) [50], while penalties can include warnings, fines and, under extreme circumstances, termination of water services.

Water restriction can take two forms [51]; outdoor use restriction (OUR) and total use constraint (TUC). In OUR, the focus is on restricting how and when watering takes place, by restricting the timing of outdoor water use (e.g. restricting outdoor water use to only certain time and day) and the manner in which water is used (e.g. for filling of swimming pool, car washing, pavement watering). However, households can still use as much water as they like, provided that this occurs for permitted water using activities during the allotted watering days. Therefore, OUR does not directly address the fundamental issues of "total use of water", denying households the opportunity to decide how to make any reductions in water their water consumption. Water restriction can also take the form of total use constraint, where the quantity of water for each household is restricted. For example, under level 6 water restriction, households in southeast Queensland will face tough penalties if they use more than 800 l/day [52]. Apart from the form, water restriction can also be either voluntary or mandatory. Studies that have examined drought management programs tend to model the presence of voluntary or mandatory restrictions as a single variable. In aggregate, these studies reported that voluntary restriction programs reduced household water use by 0% to 16%, while mandatory restriction programs reduced water use by 16% to 31% [11,20,46,47,50].

## 6. THE APPLICATIONS OF THE WDM MECHANISMS FOR LONG TERM WATER MANAGEMENT AND SHORT TERM WATER CRISIS

One of the decision pathways for water planning and management is reactionary crisis management, including drought management plans. A drought management plan focuses on mitigation and response strategies that can provide short-term relief from temporary water supply shortages. For example, during the Millennium Drought period from 1995 to 2012, southeast Australia was impacted by what was described as the worst drought on record [53]. During this period, a number of cities suffered severe water shortage problems, causing the Victorian Government to implement the WDM mechanisms to alleviate the water shortages. The Victorian Government used the mechanisms of price, technologies, communication/education and restriction to reduce household water demand in Melbourne. The implementation of the mechanisms reduced the domestic water demand in Melbourne by nearly 35%, from 247 lcd recorded in 2000/01 to 161 lcd in 2012/13 [54]. On the other hand, the water authority in South East Queensland used the mechanisms of technologies, communication/education and restriction to reduce domestic water demand. The implementation of the mechanisms significantly reduced the domestic water demand in the area by nearly 60%, from the recorded 300 lcd in 2005 to 122 lcd in 2008 [55].

It is increasingly recognized that proactive and forward thinking "risk management" approaches are more effective in mitigating effects of potential disasters or unwanted situations. This is because although some crises may be unforeseen, which requires reactionary responses, many crises related to water management, such as drought, are at least partially foreseeable. Thus, responses can be proactively planned to either mitigate the effects, avoid them entirely, or transform them into opportunities. Some regions that are prone to drought and water shortages have initiated planning for drought mitigation. For example, the Ontario Low Water Response (OLWR) is a response policy designed to improve the flexibility of the water allocation system in the event of a drought. The policy involves voluntary WDM efforts through communication/education, and mandatory restrictions when required [56]. However, despite the flexibility, in its current form, OLWR still remains largely a reaction approach [57].

Measures taken in crisis situations typically aim at meeting water demand under the prevailing water availability conditions, and hence are temporary in nature. To maintain an overall reduction in water consumption, different strategies will be required which promote a water conservation culture. Such strategies would require water managers to focus on proactive planning instead of crisis management. Some of the programs conducted by water authorities already aim to break the current reactionary approach of focusing on the benefits of water conservation primarily in response to emergencies and crisis, to focusing on the long term water management. For instance, Singapore, classed as a water-scarce country by the United Nations [58], used the mechanisms of price, technologies and communication/education to reduce domestic water demand [59]. The implementation of these mechanisms reduced the domestic water demand in Singapore by 16%, from the recorded demand of 176 lcd in 1994 to 147 lcd in 2012 [59]. In another instance, the district of South Florida, which is prone to extreme drought conditions, had prepared a water conservation plan in 2008, with the end-goal of replacing the "as needed" thinking with a more beneficial, year round water conservation ethic. In the plan, the water authority (South Florida Water Management District or SFWMD) used the mechanisms of price, technologies, and communication/education to reduce domestic water demand [60].In 2010, mandatory outdoor use restriction was also imposed, under the "Year-Round Landscape Irrigation Rule" where outdoor water use is only allowed during specified times and days [60]. In a study

conducted by the University of Florida`s Bureau of Economic and Business Research, the water demand per capita in the county of Miami-Dade, Broward, Palm Beach and Monroe fell from more than 600 liters per day (176 gallons) in 2000 to slightly over 500 liters per day (140 gallons) in 2010.

## 7. CONCLUSION

Price, technologies, communication/education and restriction were among the mostly used WDM mechanisms to reduce domestic water demand. The effectiveness of the mechanisms varies from one mechanism to another, where rainwater harvesting system was found to yield the greatest water demand reduction, while communication/education yields the lowest. Despite the different approach, most of the cities reviewed used integrated implementation of the mechanisms to reduce water demand. This shows that the mechanisms need to be combined in order to produce greater water demand reduction. Thus, effective strategies in implementing integrated mechanisms are vital in order to produce greater water demand reduction. However, currently there are still very limited studies conducted on the effective implementation of integrated mechanisms. Thus, more work is needed in order to strategize the usage of these mechanisms in maximising water demand reduction. It is expected that the work from this study will be able to assist water authorities in effectively implementing the mechanisms for a more sustainable water management.

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